PALEOMAGNETIC INVESTIGATION OF TYMOCHTEE FORMATION (UPPER SILURIAN) FROM SOUTHCENTRAL OHIO

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INTRODUCTION

Purpose

Twenty-two oriented core-samples were collected from the Tymochtee Formation (Silurian) at Plum Run Quarry, Adams County, Ohio, and were examined paleomagnetically. The purpose of the investigation was

1) to determine if this unit has a stable magnetic moment
2) to determine the declination and inclination of the stable magnetization and the position of the paleomagnetic pole defined by such a magnetic vector
3) to compare these data with Silurian pole positions previously reported for North America, and
4) to locate the stratigraphic intervals of any polarity events identified in the sequence.

The identification of a true field reversal in the rock record would be a strong indication for identifying magnetization as either depositional remanent magnetization (DRM), or as chemical remanent magnetization (CRM) that was acquired during early diagenesis. The presence of a reversal would also provide an additional means for stratigraphic correlation. Few magnetic data are available for the Lower Paleozoie rocks so investigation of magnetic directions of this time period could provide important information.

Location

Plum Run Quarry is located in south central Ohio, latitude 38°57' N, longitude 83°21' W (Jaybird 7.5 minute quadrangle map). The quarry is approximately two and a half miles east of the town of Peebles, Ohio (Fig. 1).

Structure

Plum Run Quarry is located on the eastern flank of the Cincinnati Arch just west of the Allegheny Plateau. This arch has been subjected to no major tectonic events since before the Silurian Period although it has been affected by a number of vertical adjustments, both uplift and subsidence.

Most of Ohio is free from the effects of faulting, but this area is cut by several vertical to steeply dipping faults. The quarry is located in a graben between the two major north-trending faults. Displacement on the faults is generally small with the greatest amount of displacement being twenty-five feet. Units on the western wall of the quarry have a strike of approximately N 30°E, and a dip of 4° SE (Guidebook,1961). The time at which the faulting occurred has not been determined.

Stratigraphy

The Tymochtee Dolomite is Upper Silurian (Cayugan Series) and is now generally placed in the Salina Group (Fig. 2) following the correlation of Ehlers et al, (1951). The Greenfield Formation and the Tymochtee Formation compose the Salina Group in this area. The younger Cayugan units, which belomg to the Bass Islands Group, are absent in this area as a result of post-Cayugan erosion.

Miller (1955) and Hellert (1972) measured and described the units that are exposed at Plum Run Quarry. The Peebles Formation, a member of the Niagaran Series, is the oldest unit exposed. The Greenfield Formation which is twenty-five feet thick rests unconformably on the Peebles Formation. Overlying the Greenfield Formation is approximately fifty feet of the Tymochtee Formation. These two formations are very closely related and the contact between them is gradational. The top of the Tymochtee is an unconformity showing two to four feet of relief (Hellert,1972). Immediately above this unconformity is two inches of shaly sandstone which Hellert (1972) tentatively identifies as the Hillsboro Sandstone. The Ohio Shale which has a maximum thickness of twenty-five feet is the youngest unit at Plum Run Quarry. The Ohio Shale is the present erosion and weathering surface in the quarry. However a few miles to the north and northwest of this quarry the shale is absent and the Tymochtee has been exposed and is being subjected to erosion and weathering.

On the basis of the internal sedimentary structures of the Tymochtee and the Greenfield, Hellert (1972) concluded that these two units were deposited during a marine regression. He considers the Greenfield Formation and the Lower Tymochtee Formation to have been deposited in an intertidal environment, and the Upper Tymochtee to have been deposited in a dominantly supratidal environment. Kahle and Floyd (1971) made studies of the Greenfield and Tymochtee Formations and concluded that the dominant environment of these beds in northern Ohio was intertidal and they predicted that evidence for a supratidal flat would be found in the Cayugan rocks to the south.

Sedimentary Characteristics and Mineralogy

The dominant mineral of the Tymochtee Formation is dolomite. Hellert states that 80-90 % of the units are composed of this mineral. Most units are also argillaceous. Illite is the most common clay mineral but some chlorite is also present (Hellert,1972). Fine grained quartz is fairly abundant and feldspar is found in small amounts. Pyrite is a common secondary mineral. Miller (1955) reports that pyrite usually constitutes 10-30 % of the non-carbonate minerals. A higher percentage of pyrite is found in the upper beds which are just below the Ohio Shale.

Hellert (1972) concludes that dolomitization occurred during early diagenisis. Because of the grain size differences, Hellert suggests that dolomitization of the upper, fine crystalline Tymochtee occurred penecontemporaneously with deposition. Dolomitization of the lower, medium grained Tymochtee occurred a short time after deposition.

Distorted beds and brecciation are observed in the Tymochtee Formation. Hellert (1972) believes that brecciation occurred as a result of periods of alternate flooding and aeration of the depositional site. These breccias do not provide a means of applying the "conglomerate test" (Graham, 1949) to the formation as a means of determining if the magnetization was acquired by the addition of magnetic detritus during deposition (DRM). Dolomitization occurred concurrently with and after brecciation so that the intercrystalline structure was fairly open at a time when the sediment still contained excess water. The open structure and expulsion of water during compaction could have permitted the magnetic minerals to rotate into alignment with the earth's magnetic field.

The characteristics of the Tymochtee Formation are quite variable. The insoluble residue may range from less than 2 % in some units to as much as 20 % in other units. The content of insoluble residue in the upper Tymochtee is higher than the content in the lower Tymochtee

(Hellert, 1972). The Tymochtee varies in color from dark brown to light tan and from grey to light grey with mottling of the grey and light grey being commonly observed.

Some of the units show large vuggy porosity while others show scattered, very fine vugs. Many of the vugs contain a carbonaeeous residue, Some of the units are dense and show no porsity. The fact that some of the units are vuggy and contain carbonaceous residue, indicates that formation waters flowed through some of the beds after deposition even though permeability seems to be low in the units now.

Paleomagnetic Investigation

Collection and Preparation of Field Samples

Twenty-four cores, one inch in diameter, were collected and oriented by sun compass in the field. Collections were made by T. Davenport and J. Hellert. Baird (1971) gives a detailed explanation of the field procedure used. Eight of the cores were collected from the Lower Tymochtee (approximately 18 feet in thickness) and the remaining sixteen cores were collected through the upper 28 feet of the formation. The cores were taken at two- to three-foot intervals in the formation. Two of the cores broke apart during laboratory preparation and were not used. The stratigraphic relationship of the twenty-two cores measured are shown in Figure 3.

Laboratory Investigation

The cores were cut into one-inch lengths and the magnetic vector of each sample was measured in a spinner magnetometer. Most of the cores were taken through a demagnetization sequence (single axis AF demagnetizing unit) in 50 oersted steps through a maximum demagnetizing field of 300 oersteds. For details of the laboratory procedure and a description of the equipment used see Baird (1971).

The total magnetic intensity, the intensity normalized to the initial intensity of the undemagnetized core and the direction of the magnetic vector corrected to its ~~field~~ original position were calculated for each sample at each demagnetization level on the Ohio State University IBM 360.

Discussion of the Experimental Results

The magnetic moment measured in a sample prior to demagnetization is referred to as natural remanent magnetization (NRM). It is assumed that this magnetic moment is the sum of the magnetic moments acquired naturally and in the field. Other factors may contribute to the magnetization measured in the undemagnetized sample if the samples have a weak magnetic moment. These factors include the magnetic moment contributed by metal contamination acquired during the coring process and contamination by ink used to mark orientation and identification information on the core. If the rock contains a soft magnetization component, then storage in the laboratory will cause the soft component to rotate into alignment with the laboratory field.

The Tymochtee samples were stored in the laboratory for a period which varied from several weeks to several months before initial measurements were made and it is possible that the NRM directions recorded contain some response of the soft component to the laboratory field.

Furthermore, eight of the samples were marked with ink. Therefore, Figure 4 which shows the directions of the undemagnetized samples probably does not accurately show the directions of the units in the field. However, the effect on the NRM directions caused by ink contamination and rotation of the soft component during laboratory storage does not appear to be great, because these will usually randomize the directions whereas the NRM directions cluster closely to the present-day field at the collection site (Fig. 4). The steep inclination and a declination into the northern hemisphere shows a response to the present-day field at Plum Run Quarry by the soft magnetic component present in the rocks.

Figure 5 shows the normalized decay curve (J_i/J_o) of the total magnetic moment for one of the samples, JA, during the demagnetization sequence. J_o is the measured intensity prior to demagnetization and J_i is the intensity after demagnetization at the peak field indicated. In general the effect of the ink markings on the magnetic intensity of the samples caused an increase in the NRM intensity. Of the eight samples marked with ink, six showed a decrease of 45 % or greater in the intensity after demagnetization in a peak field of 50 oersted. The intensity of two of these samples decreased by 65 % and 75 %. By contrast none of the unmarked samples that were demagnetized at the 50 oersted level had a decrease greater than 45 %. One of the ink-marked samples showed a slight increase in the strength of the total moment following demagnetization at 50 oersted.

The results of previous experiments indicate that the contamination due to ink markings is probably removed after demagnetization in a peak field of 150 oersteds. Figure 5 gives two values for J_i/J_o after demagnetization in a field of 200 oersteds. One of these represents the values recovered before the ink markings were removed and the other, the value recovered after buffing the sample on a carborundum wheel to remove the markings. Figure 6 shows the migration of the magnetic moment for sample JA during the demagnetizaton sequence. Two values are given for the 200 oersted level which represent the directions measured prior to and following removal of the ink markings. The results indicate that at least for sample JA, the effects of ink contamination were removed before demagnetization at the 200 oersted level. The ink markings were removed from all eight samples before the final demagnetization and measurement of the sample.

For the most part the performance of the samples during laboratory experimentation was not satisfactory. The samples are weak, although they are within the range of measurement by the laboratory equipment. However, care was necessary to prevent contamination of the sample holders due to dust in the laboratory and particles from strongly magnetic igneous rocks being run concurrently. Another problem with these samples was that most of the samples have a large soft magnetic component compared to the hard magnetic component. The soft magnetization becomes readily aligned in any stray field and effects the directions measured. The effects of this soft magnetization became observable in all except three of the samples by the time the 300 oersted level of demagnetization was reached. In some of the samples magnetic instability developed at lower levels of demagnetization. When a second measurement was taken on a sample, a change in direction resulted which indicates the magnetic instability. This occurred whether the sample was redemag- ?? netized at the same level or was measured again within twenty-four hours without being demagnetized again.

All of the samples except one, JG, showed a definite migration into the southern hemisphere. One of the samples, JH, seems to have a direction distinctly different from that of the other samples (Fig. 7). This sample is one of the more stable of the group as might be expected because the NRM direction was less affected by the present field.(Fig.4).

A satisfactory clustering of magnetic directions did not appear after demagnetization. An examination of Figure 7 shows that the declinations of the demagnetized samples are spread between 150° and 180°. It appears to be a reasonable assumption that the magnetic directions of Figure 7 do not represent a single group magnetically.

To test the possibility that the samples fall into two groups magnetically, those samples with declinations clustering near 160° (Group A) were treated separately from those with declinations clustering around 180° (Group B). Calculations for the mean magnetic directions, Fisher statistics and paleomagnetic pole positions were made on both of these two groups as well as on all the thirteen samples which seem to have a fairly stable magnetic moment following demagnetization in a peak field of 300 oersteds. The results of these calculations are given in Table I. The statistical data are slightly improved when the samples are treated as two separate groups than as a single group.

A comparison of the Group B directions obtained from the Tymochtee was made with information recovered from the Upper Devonian Columbus Limestone (Fig. 9). The paleomagnetic pole calculated from the Group B directions is located considerably to the west of the virtual geomagnetic pole obtained for three samples collected from the Columbus Limestone near Columbus, Ohio (Greaney, 1972).

The paleomagnetic pole position of the Group B suite was also compared with published Permian pole positions. Roy, Opdyke, and Irving (1967) and Irving and Opdyke (1965) reported an unstable magnetic component which they interpreted as a Permian overprinting in the Bloomsburg Formation of Upper Silurian age. The reported Permian pole positions are generally located east of those for the Tymochtee Group B samples (Fig. 9) The poor correlation suggests that Group B does not reflect a Permian stage of magnetization and on the basis of the present data there appears to be no reason for separating Group A and Group B.

The two paleomagnetic investigations of the Bloomsburg Formation (op.cit 1965, 1967) are of particular interest to the present study because the Bloomsburg is lower Cayugan in age and may in part be a stratigraphic equivalent of the Tymochtee Formation (Fig. 2); therefore a brief review of the pertinent observations is given. In both investigations of the Bloomsburg Formation a stable magnetic component having normal polarity was identified. The authors interpreted this magnetic moment as a Silurian magnetization. In both investigations an unstable reversed magnetization was also identified. The authors interpreted this unstable component as a later magnetic imprinting probably acquired during a tectonic event of the Permian Period. As well as the component attributed to overprinting during the Permian Period, Roy, Opdyke and Irving (1967) also observed a reversed component, oriented approximately 180° from the normal stable component. The authors tentatively suggested that this vector is a valid Late Silurian magnetization. However, because they did not feel that they could with certainty distinguish it from the unstable reversed moment they did not include it with their Silurian data. In view of the observation that the Tymochtee is reversely magnetized and in view of the fact that both the Bloomsburg and the Tymochtee are now assigned to the Salina Group, it is possible that important information concerning the relative ages of the two formations can be deduced by defining the stratigraphic relationships of the reversed sequence of the Bloomsburg units.

One of the main purposes of the investigation of the Bloomsburg Formation by Roy, Opdyke and Irving (1967) was to test the hypothesis that the curvature of the Valley and Ridge Province in Pennsylvania was imposed during Late Paleozoic tectonism. The authors interpret their data as demonstrating that a simple bending of the Appalachian Arc did not occur. The paleomagnetic pole of the Tymochtee Formation calculated on the basis of this study is not significantly different from the pole positions calculated on the basis of the two sites of Bloomsburg samples (Fig.8) and shows that there ~~was~~ has been no rotation of the Pennsylvania region relative to the southern Ohio region since late Silurian time. In contrast the paleomagnetic pole positions calculated on the basis of the Rose Hill Formation (Lower Silurian) and Clinton iron ores (Lower Silurian) are significantly different from those calculated for the Cayugan suites (Fig.8). The divergence in the position of the paleomagnetic poles calculated for the

Lower Silurian units and for the Upper Silurian units probably indicates a displacement of the North American plate relative to the geomagnetic pole following magnetic imprinting of the older units.

Conclusions

The samples taken from the Tymochtee Formation for paleomagnetic investigation did not respond well to demagnetization in an alternating field. The preferred orientation of the magnetic vectors is toward the southern hemisphere. There is quite a large amount of scatter in magnetic directions following demagnetization. Examination of the distribution of the magnetic directions following demagnetization can be interpreted as suggesting smearing through the present-day magnetic field along two great circles. However, the effort to treat the directions as distinctive and as arising as a result of two different magnetic events failed when comparison showed that the anomolous group (Group B) does not give a probable pole-fit to poles determined for post-Silurian units. The scatter is primarily due to a relatively large, unstable magnetic component introduced as a result of the alteration of pyrite.

Only reversed directions were encountered within the Tymochtee. This observation together with the rather large scatter in directions does not permit the use of paleomagnetic directions to assist in refining local correlations within the Tymochtee Formation.

The paleomagnetic pole position calculated on the basis of samples taken from the Tymochtee Formation is located at a latitude of 36.6° N and a longitude of 108.8° E. This paleomagnetic pole position is not significantly different from the two pole positions previously determined for the Bloomsburg Formation. The agreement of the Ohio data with the Pennsylvanian data indicates that the two areas have been part of the same tectonic plate since Late Silurian time.

The difference in paleomagnetic pole positions determined for Lower Silurian rocks and Upper Silurian rocks is best explained as a translation during Middle Silurian time of the North American plate relative to the geomagnetic pole.

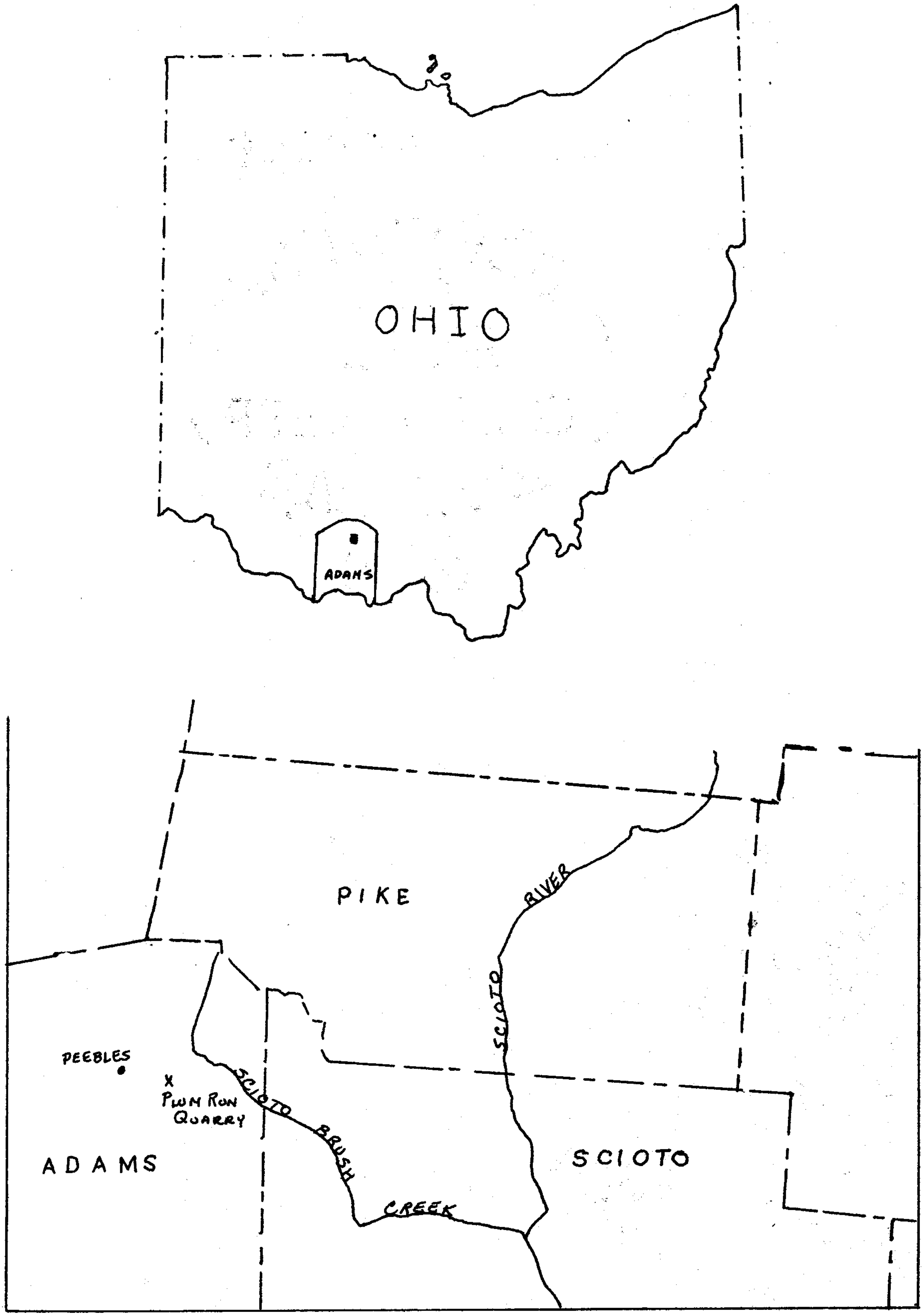


FIGURE 1. LOCATION OF PLUM RUN QUARRY.

Chart No.3. CORRELATION OF THE SILURIAN FORMATIONS OF NORTH AMERICA

By C.K.Swartz, F.J.Alcock, C.Butts, G.H.Chadwick, E.R.Cumings, C.E.Decker, G.M. Ehlers, A.F.Foerste, T.Gillette, E.M.Kindle, Edwin Kirk, S.A.Northrop, W.F.Prouty, T.E.Savage, R.R.Shrock, F.M.Swartz, W.H. Twenhofel, and M.Y.Williams

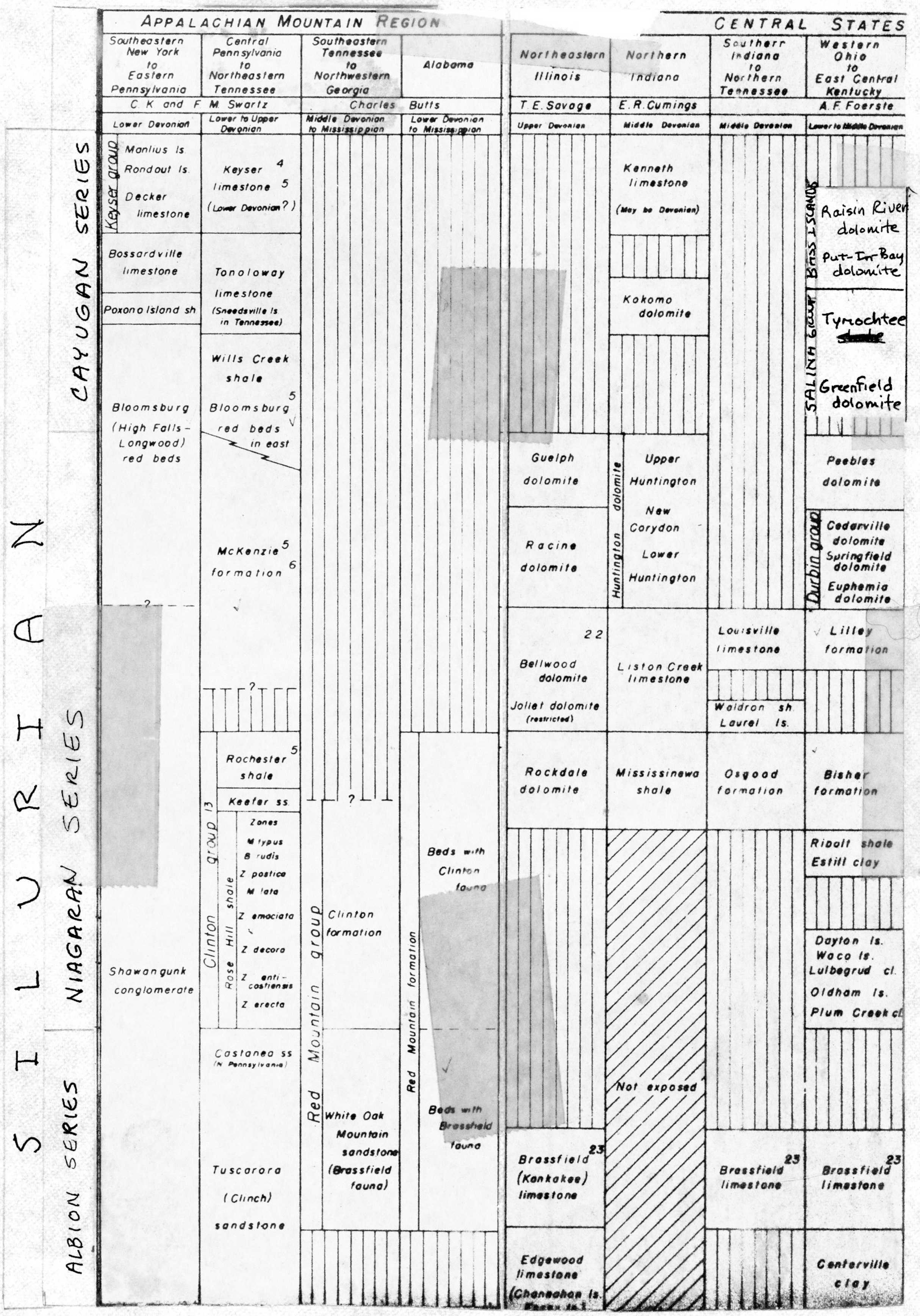


Fig.2. Correlation chart

Figure 3. Stratigraphic relation of samples collected for paleomagnetic investigation. The specific stratigraphic level of each sample is only approximately located.

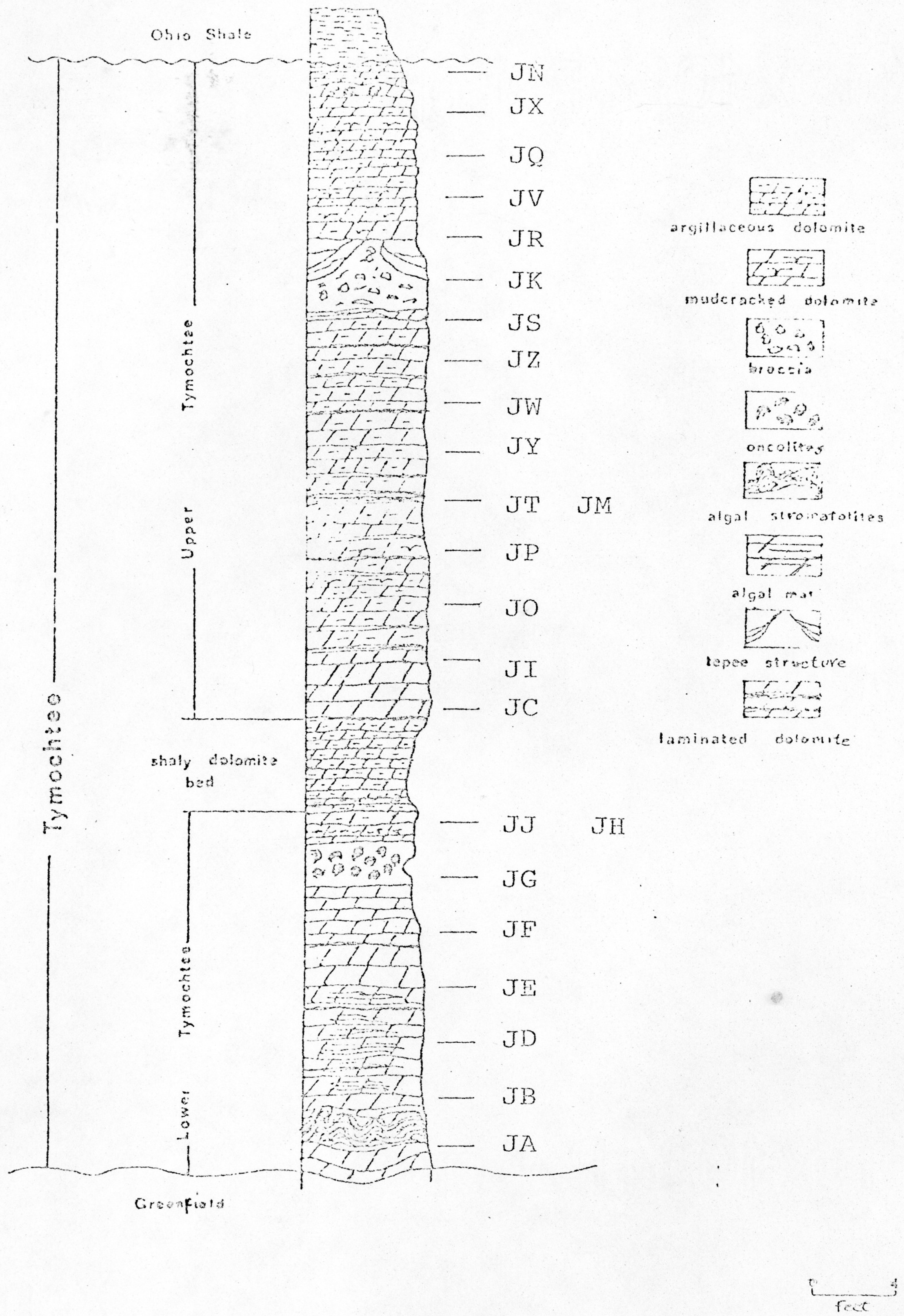

Ohio Shale
JN
JX
JQ
JV
JR
JK
JS
JZ
JW
JY
JT
JM
JP
JO
JI
JC
Upper Tymochtee
shaly dolomite bed
Tymochtee
JJ
JH
JG
JF
JE
JD
JB
JA
Lower Tymochtee
Greenfield
argillaceous dolomite
mudcracked dolomite
breccia
oncolites
algal stromatolites
algal mat
tepee structure
laminated dolomite
0
4
feet

Figure 4. Equal-area stereonet showing distribution of magnetic directions in twenty-two Tymochtee samples prior to demagnetization. All inclinations are positive (i.e. downward).

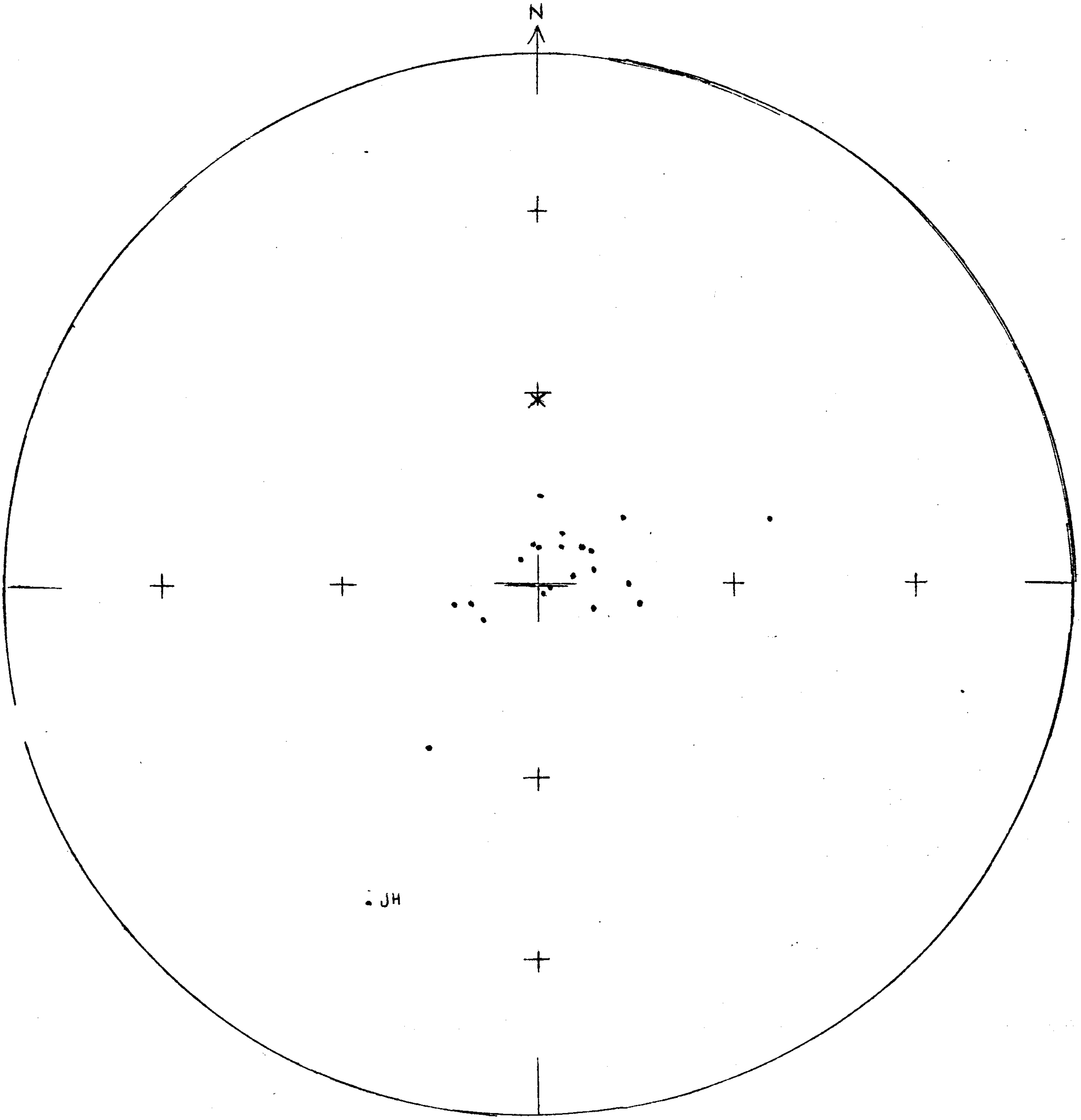
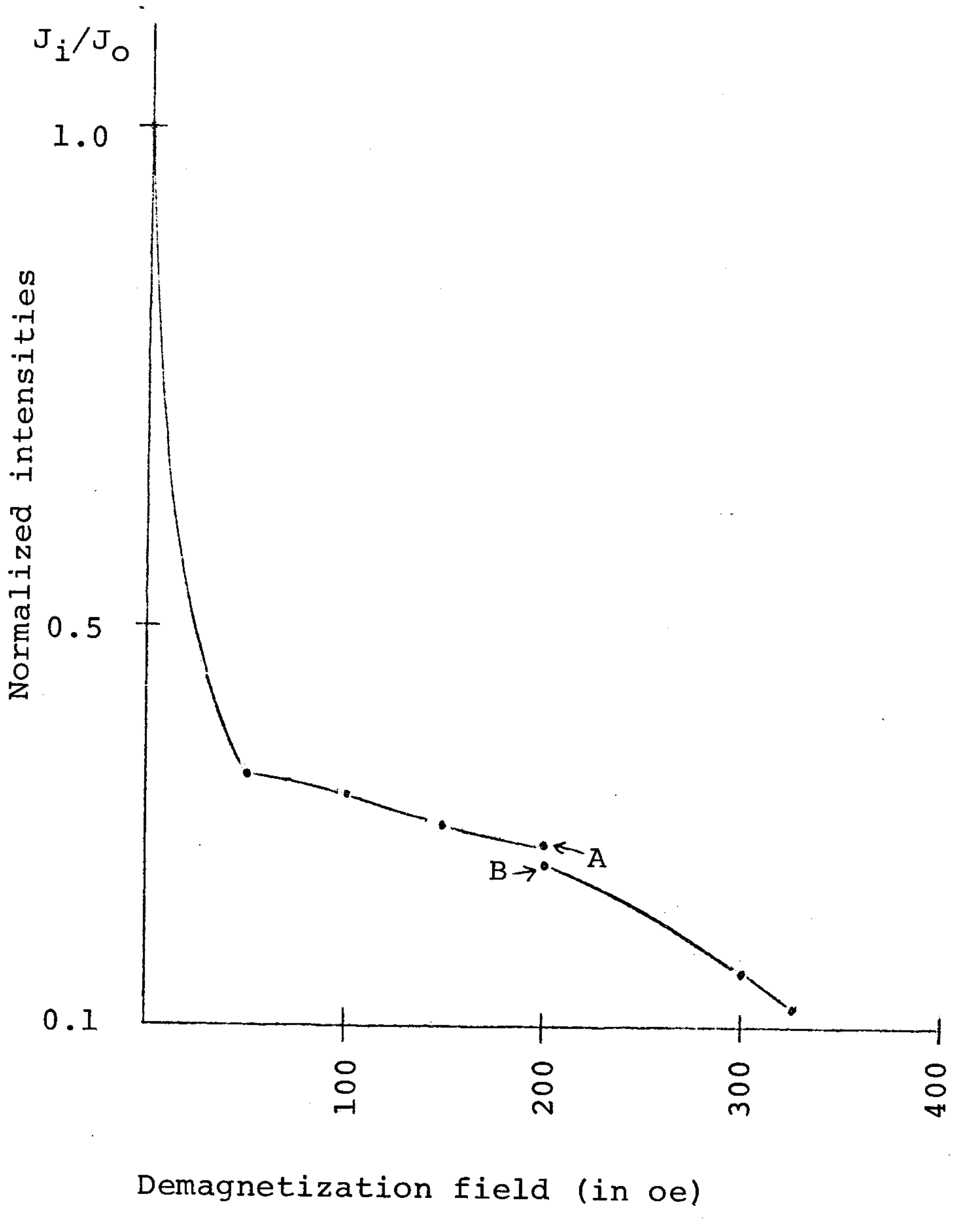
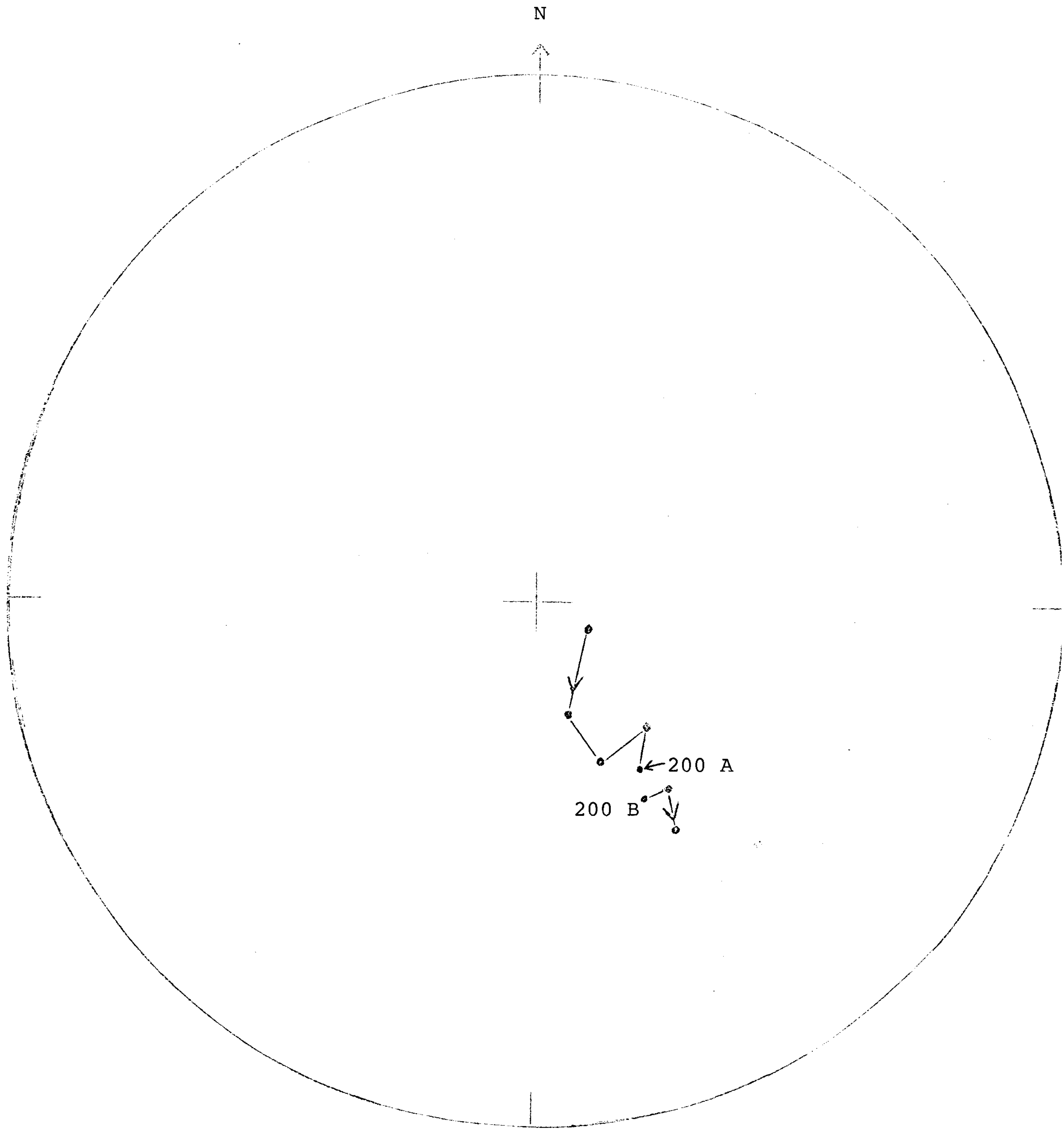

N
JH

Figure 5. Normalized decay curve of magnetic intensities for sample Ja during AC demagnetization.



J_i/J_o
1.0
0.5
0.1
Normalized intensities
A
B
100
200
300
400
Demagnetization field (in oe)

Figure 6. Migration of magnetic vector during demagnetization of sample JA.


N
200 A
200 B

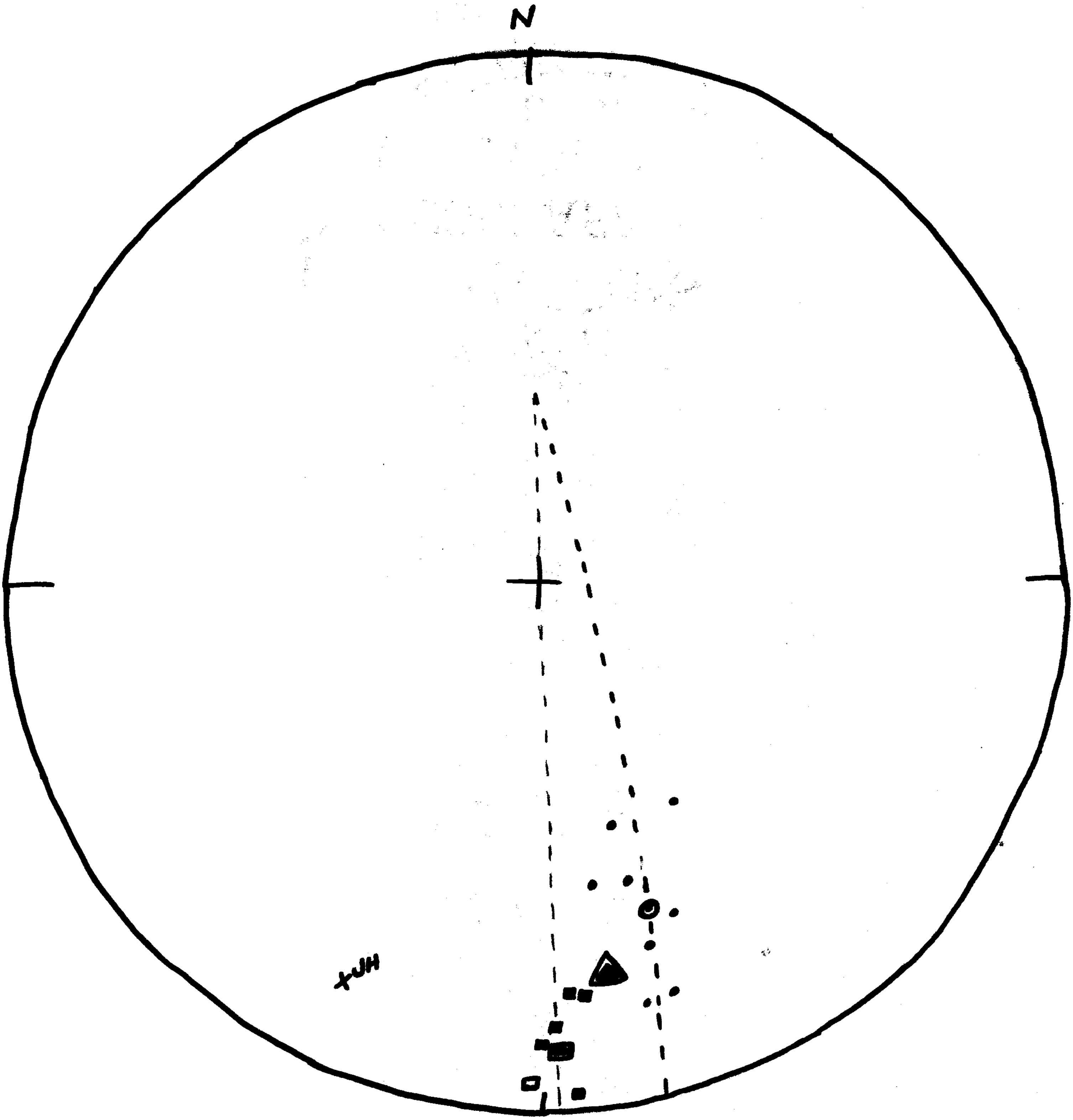


Fig.7. Final directions being used and mean declination and inclination
Group A and Group B
A and B combined

- Group A
- Group B Inclination positive
- Inclination negative

- Mean Dec Incl Group A
- Mean Dec Incl Group B
- Mean Dec Incl Combined

Figure 8. Paleomagnetic pole positions for Silurian rocks. A pole position based only on Group A directions (1A) and on the combined Tymochtee directions (1C) are shown. The latter pole position is preferred for the Tymochtee Formation. (See Table I for numbered references)

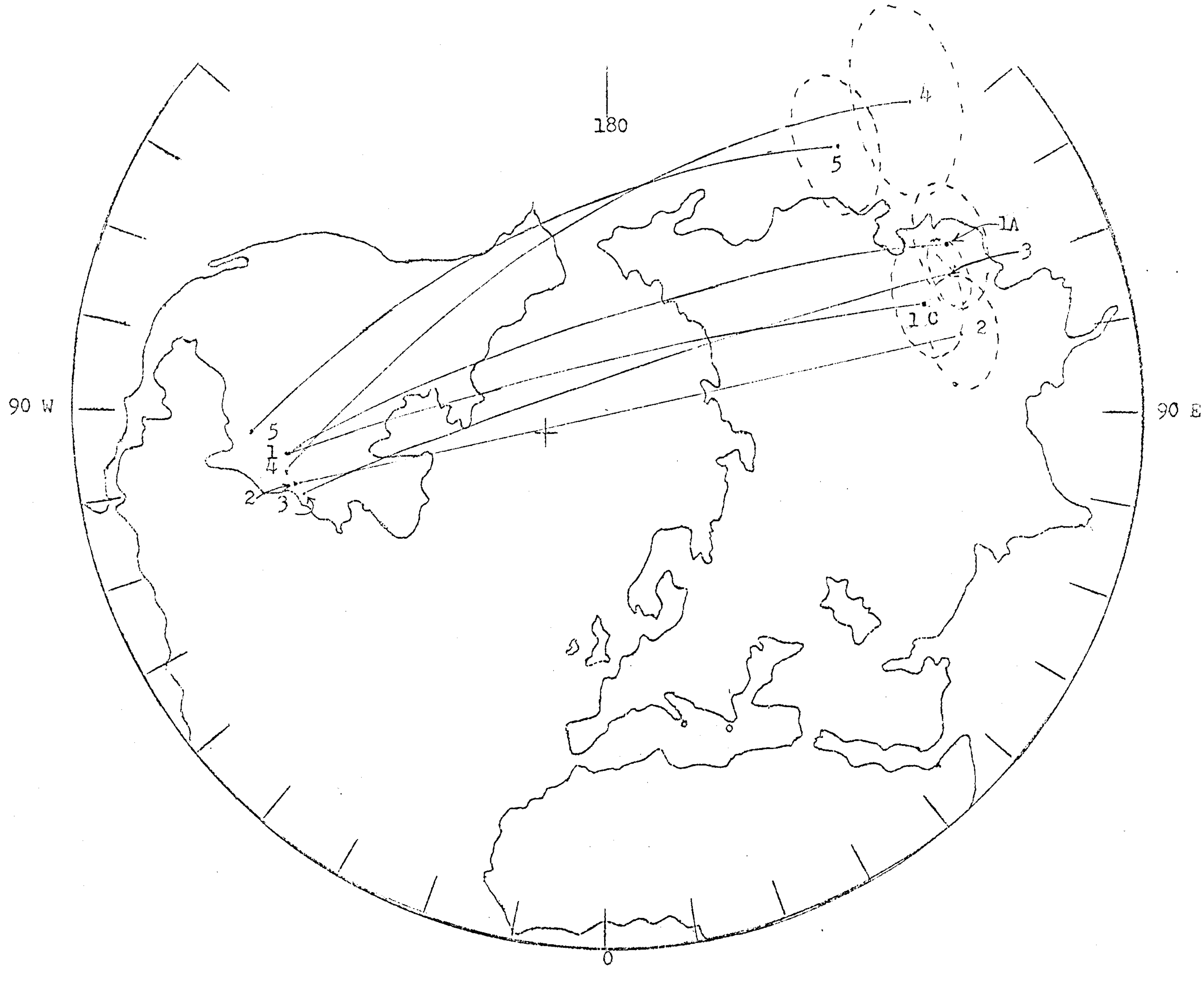
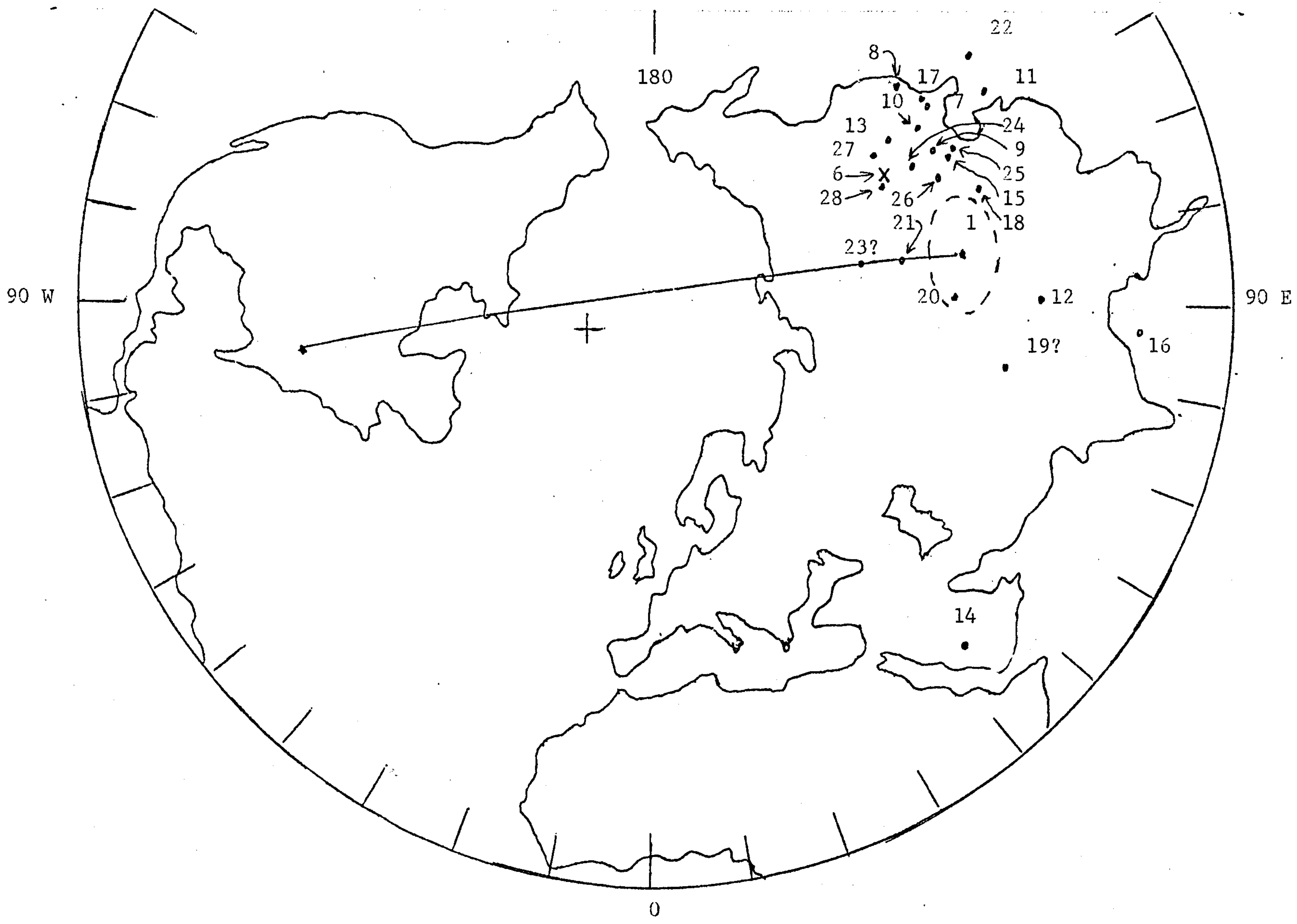

180
90 W
90 E
0
4
5
1A
3
1C
2
5
1
4
2
3

TABLE I

REF. NO. Fig. 8	Formation	Lat.	Long.	D_m	I_m	k	α_{95}	Paleomagnetic Pole Lat.	Paleomagnetic Pole Long.	δ_m	δ_p
1 A	Tymochtee (Group A)	38.6	-83.2	161.9	34.9	42	8.6	29.4	116.4	10	5.7
1 B*	Tymochtee (Group B)	38.6	-83.2	177.8	12.3	48	9.7	44.8	99.7	10	5.0
1 C	Tymochtee (Combined)	38.6	-83.2	170.0	25.9	19	9.7	36.6	108.8	10.5	5.7
2	Bloomsburg (a)	40.0	-77.5	10.0	-32.0	35	9.0	32.0	102.0	10.0	6.0
3	Bloomsburg (b)	41.0	-74.5	354.0	-32.0	62	5.0	31.0	112.0	6.0	3.0
4	Clinton	33.6	-86.7	143.0	19.0	107	12.0	34.0	139.0	12.0	7.0
5	Rose Hill	39.5	-79.0	325.0	-39.0	33	13.0	20.0	136.0	15.0	10.0

* See Figure 9

Figure 9. Comparison of paleomagnetic pole position based on Group B directions with the virtual geomagnetic pole for the Devonian Columbus Lst. and with reported Permian pole positions. The paleomagnetic pole position for Group B directions is located considerably west of the area in which most of the pole positions cluster. (See Table II for numbered references)



180
22
8
17
11
10
7
13
24
27
9
6
25
28
26
15
18
21
1
23?
90 W
20
12
90 E
19?
16
14
0

TABLE II

REF. NO. (FIG. 9)	FORMATION	REFERENCE
1.	Tymochtee (Sil.)	This study
6.	Columbus (Dev.)	Greaney (1972)
7.	Redbeds (Carb.-Perm.)	Black (1964)
8.	Redbeds (Carb.-Perm.)	Roy (1966)
9.	Basic Intr. (Carb.-Perm)	Larochelle (1967)
10.	Dunkard Series (Perm.)	Helsley (1965)
11 & 12	Cutler (Perm.)	Graham (1955)
13	Cutler (Perm.)	Farrel, May (1969)
14	Cutler (Perm.)	Helsley ( )
15 & 16	Abo (Perm.)	Graham (1955)
17	Yeso (Perm.)	Graham (1955)
18	Supai (Perm.)	Runcorn (1955a,1956a) Doell (1955) Graham (1955) Collinson, Runcorn (1960)
19.	Sangre de Cristo (Penn.?)	Graham (1955)
20.	Hermit (Perm.)	Farrell, May (1969)
21.	Toroweap (Perm.)	Farrell, May (1969)
22.	Lower Maroon (Perm.)	McMahon, Strangway (1968)
23.	Upper Maroon (Triassic?)	McMahon, Strangway (1968)
24	Fountain-Lykin (Perm.)	McMahon, Strangway (1968)
25.	Wolfcampian Series (Perm.)	Peterson, Nairn (1971)
26.	Leonardian Series (Perm.)	Peterson, Nairn (1971)
27.	Guadalupian Series (Perm.)	Peterson, Nairn (1971)
28.	Ochoan Series (Perm.)	Peterson, Nairn (1971)

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